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Thermal processing of waste organic substrates: Developing and applying an integrated framework for feasibility assessment in developing countries

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ABSTRACT

Against the background of global climate change and increasing prices of fossil fuel, the importance of producing sustainable renewable energy increases significantly. CO_2-neutral energy generation using biomass or organic waste is an alternative option that deserves attention particularly in developing countries. Aim of this paper is to provide an integrated framework for the preparation of feasibility studies for the renewable energy sector there, considering technical, environmental, economic, socio-cultural, legal and institutional aspects which are particular applicable for developing countries. Such a feasibility framework involves a definition of the scope, which reflects the aims and objectives of the target groups (supplier, operator, etc. of renewable energy supply) and the methodologies and tools involved. All relevant aspects are covered: data collection, selection of sites and assessment of options. Furthermore, methods and tools for risk assessment and decision-making are presented and a practical plan of procedures is last provided. The proposed framework is then applied to a selected area in Vietnam and certain results of the study, showing that the implementation of a biogas plant utilizing organic waste would be feasible, are presented in this paper.

Contents

1. Introduction

Renewable energy (RE) production using organic waste and biomass is particularly interesting for decentralised applications in developing countries, either for the production of biogas or directly by burning as a fuel. Due to climatic conditions and economic structures, organic substrates from agriculture, forestry, households and industry are often very abundant. Biomass can therefore provide an environmentally, economically and socially sound energy supply for private households and industry alike [1].

Objectives of the here proposed framework are to aid with the production of integrated feasibility studies for the renewable energy sector, considering all aspects which are particularly applicable for developing countries. It involves a definition of the

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scope, which reflects the aims and objectives of the target groups, methodologies and tools which provide answers to questions such as: why is it useful to do a feasibility study for RE; what needs to be done; who can help; what needs to be taken care of; and, how much detail is needed. Relevant aspects covered include data collection, selection of sites and options, as well as how to assess the feasibility of options, including technical, environmental, economic, social, cultural, legal and institutional aspects. Furthermore, methods and tools for risk assessment and multi-criteria decision-making analysis are presented.

Generally, the main obstacle when implementing new sustainable strategies like renewable energy by biogas or biomass combustion is the lack of information on feasible options. Information in the form of guidelines can help to overcome these obstacles and aid with the planning of renewable energy projects. Increasing the awareness regarding RE supply options derived by organic substrates can help in achieving political goals such as reducing the pollution, promoting eco-tourism and providing cost-effective, decentralised energy supply for the inhabitants; it can form the ground for policy developments and further activities regarding Clean Development Mechanism projects on the basis of the Kyoto Protocol [2]. Clean Development Mechanism (CDM) was designed for promoting cooperation between developing and developed countries by allowing the latter to invest in GHG emissions abatement projects in the former. Under the CDM, developed countries can invest in emission abatement projects in developing countries and receive credits. Fig. 1 illustrates the allocation of CDM projects worldwide according to their focus area, while Fig. 2 shows the emissions reduction desegregation planed by the implementation of CMD.

CDM may add to economic viability of projects that are already economically sound, while also facilitating technology transfer. Appropriate public–private linkage would be necessary in order to bring the CDM into full play. With the potential value of CDM taken into account, there is a chance of economic viability of the combined scenario, which is also the best from the CO_2 emissions viewpoint. The CDM represents an opportunity to attract investments from the public and private sectors in climate-friendly technologies and to contribute to the global combat on climate change. In order to be eligible, CDM projects have to be above and beyond business-as-usual and must contribute to sustainable development as defined by the host country; one of the sectors with major potential for CDM projects is the energy sector. The CDM offers a route to attracting investment to rehabilitate existing sites and new facilities. The CDM was proposed in the Kyoto Protocol as a means of obtaining the cooperation of developing countries in controlling GHG (cf. Fig. 2), but it has some intrinsic problems and has generated considerable controversy as listed below, as CDM projects [4]:

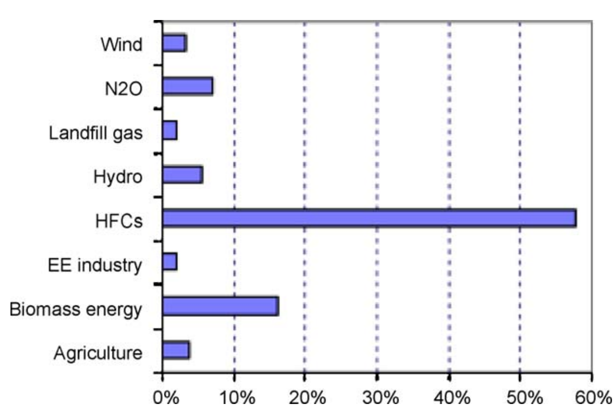

Fig. 1. CDM projects to date [12].

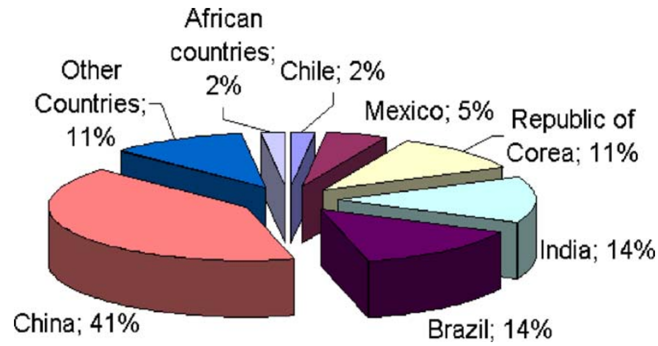

Fig. 2. CDM emission reductions [12].

- May cause carbon leakages within the host country or/and domestic carbon leakages because the CDM is project-based. Abatement activities of the CDM projects might result in a movement of the GHG emissions into the non-CDM projects. Currently, few CDM projects take account of the leakage effects, as the insufficient leakage accounting will affect the evaluation of the CDM projects.
- Are project-based so the host country government and business communities must have a good understanding about the mechanism and good knowledge about information search, negotiation, validation, registration, monitoring and certification, a need which is very challenging for many developing countries.
- Put forward a number of concerns for developing countries:
  (a) CDM investors would choose the most lucrative projects and leave DCs with only high-cost options.
  (b) CDM would interfere with national sovereignty and distort development priorities.
  (c) The CDM was proposed for environmental and development concerns, but the investment in CDM projects is mainly a business activity rather than an environmental protection action or an aid for development likely to exhaust the DCs' low-cost abatement options with little promotion for their sustainable development.

New technology is a way of developing towards a sustainable society consistent with developing countries' socio-economic priorities (development and quality of life) [5]. An issue that is being evaluated within EU and many developing countries cooperation of is the one of technology transfer (and not transform) identified also on CDM, which will allow developed countries to invest in low-cost abatement opportunities in developing countries. In this case these countries get the trading gains or the scarcity rent that developed ones have legitimately extracted [6,7]. Past experiences indicate that a successful technology transfer requires careful consideration of certain requirements from both the industrialised countries and DCs [8]. Governmental and local authorities should be informed and investigate the conditions under which circumstances "technology transaction and not technology transfer" is performed and estimate their capability to assess, select, import, assimilate, adapt and develop the appropriate technologies [9].

Developing countries, often being medium- to large-scale economies, should give preference to locally provided manufactured units which have been proven successful and select simple technologies and low-technology options. Waste-to-energy systems are a characteristic example of those referred above; urban waste generated in several of such countries can be approximately 50–70% putrescible on a wet weight basis. On

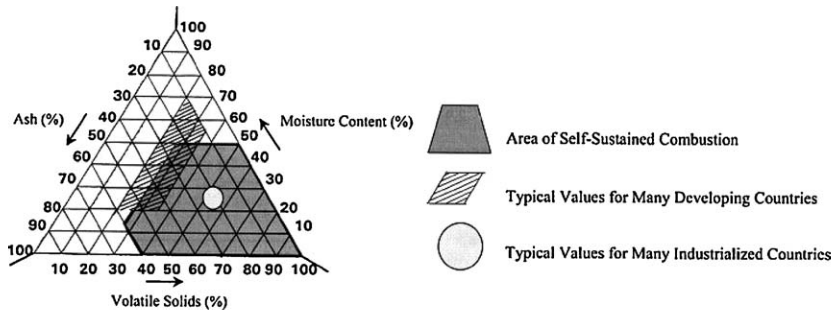

Fig. 3. Thermal characteristics of MSW in terms of self-sustained combustion [5].

the other hand, the percentiles of discarded paper and plastics are relatively small. Therefore, the overall percentage of dry, combustible (volatile) matter is small [10]. Additionally, the ash content of urban waste in some locations in DC can be substantial (e.g. up to 60% where wood ash, coal ash, or both are the major waste byproducts of domestic activities). The combination of these attributes of the wastes can render the waste conversion system as a net user of energy as opposed to a net supplier. The relation among fundamental parameters is illustrated in Fig. 3.

Conversion of waste biomass and organic substrates into energy encompasses a wide range of different types and sources of biomass, conversion options, end-use applications and infrastructure requirements. Many of the processes are suitable for either the direct conversion of biomass or the conversion of intermediate types of biomass (cf. Fig. 4).

Factors that influence the choice of a conversion process include the type and quantity of biomass feedstock and the desired form of the produced energy, i.e. end-use requirements; environmental standards; economic conditions and other project-specific factors [11]. Compared with other energy projects, bioenergy projects are likely to have large positive socioeconomic and environmental impacts for two reasons. First, biogas and thermal plants can be realised on a relatively small scale and are therefore suitable for decentralised solutions. Secondly, new added value supply chains and local bio-economies can be developed in rural areas [12].

2. Introduction to feasibility assessment

It is well known that a feasibility study is a preliminary study undertaken prior to implementing a project in order to ascertain the likelihood of the project's success. As the name implies, it is an analysis of the viability of an idea. The focus is on answering the essential question of whether the proposed project idea should be implemented. A feasibility study is often also an analysis of possible alternative solutions to a given problem, especially highlighting the different impacts of these alternatives and also including a recommendation on what is considered the best alternative.

Before starting a feasibility study, a pre-feasibility study may be conducted first to help sort out relevant alternatives. It is important to carefully evaluate the market in which the project is placed with care; sometimes, a feasibility study can be pre-empted when there is no sufficient economic incentive for a project. In the case of projects in energy production from biomass in developing countries, this assessment is relatively straightforward: In most lightly populated and rural areas, especially in developing countries, reliable electricity as well as better waste management is needed. Once a pre-feasibility study has been done and it is clear that the project is generally possible and viable, then the more detailed feasibility study of the remaining alternatives is to be undertaken.

For efficient data collection, it is advisable to do a two-step collection. The first step can be done via a pre-feasibility study. If

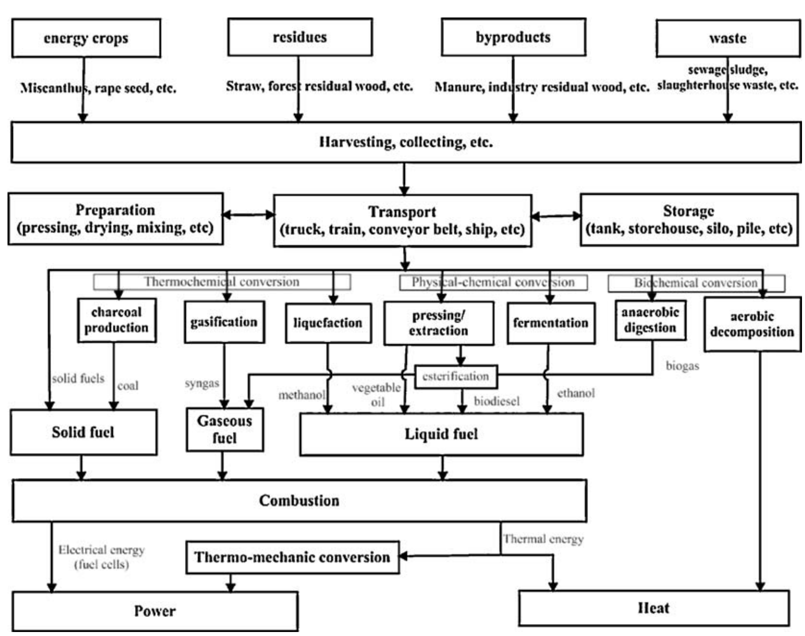

Fig. 4. Overview of RE production from organic substrates [3].

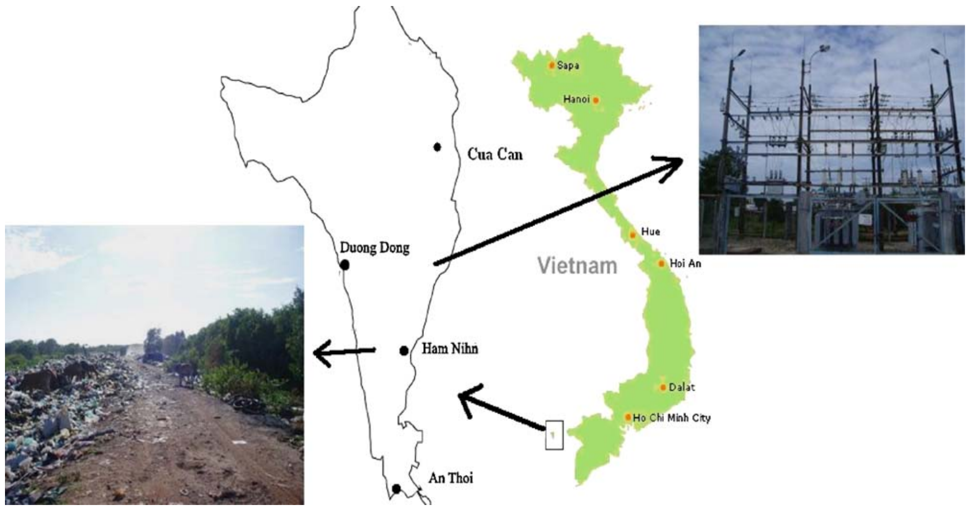

Fig. 5. Map of Phu Quoc Island also showing the location of the proposed biomass utilization sites, as well as the waste management and electricity grid situation at the study period.

no such study is done, then the data collected in the first step should look upon the following subjects:

- RE from organic waste (i.e. energy supply and demand, substrate availability, etc.),
- policy framework,
- environmental considerations (environmental impact of the project),
- economic aspects (costs of the project, funding availability).

A feasibility study generates in-depth information about a project and the factors that surround it. It serves the purpose of informing all members of the project about it. This will help the project leaders and decision makers to come to a decision on whether the project will be implemented and if so, which option or alternative is to be preferred. However, there will often not be a single answer or one option generated by a feasibility study, as the decision of whether or how to proceed often is not clear cut. Sometimes major weaknesses of the project are discovered, some of which can be overcome, whereas the study will mainly help to assess the trade-offs between risks and rewards of the project. A feasibility study should not be confused with a business plan, neither shall it start with the assumption that the project will be implemented anyway, as this could make it difficult to evaluate whether the project can be basically useful at the first place.

3. Framework condition for renewable energy on Phu Quoc

The Phu Quoc district is an archipelago of Vietnam located in the gulf of Thailand and takes a very important place in the development of aspects of national security and economy (cf. Fig. 5). The Phu Quoc district consists of the Phu Quoc Island, the An Thoi archipelago, the Tho Chau archipelago and other 36 islands. Phu Quoc island is the biggest island in Vietnam. In 2005, 88,304 inhabitants were living in 18,792 households, with the average population density being about 144 cap/km^2 and the mean annual population growth rate 1.7%. A lot of Phu Quoc's inhabitants come from other areas to work in the island's expanding fishing industry [13]. In accordance to Vietnam's national planning, the development in Phu Quoc Island has to focus on objectives such as:

- Sustainable development of agricultural land to produce clean, high-quality products suitable for eco-tourism.
- Development of clean industries to create jobs and produce goods, by establishing some small industrial zones (2–5 ha each) near the residential area.
- Development of public networks (i.e. roads, power grid, and connection to the mainland).

Initial study findings revealed that there is no restriction on the production of renewable energy from organic waste and biomass in Phu Quoc island, as both local and central government highly support the introduction of RE and waste treatment technologies on the island. The establishment of environmentally sound practices in the field of energy production and waste management is regarded crucial to ensure a future sustainable development and, as a result, the framework conditions on the island of Phu Quoc were found to be very favorable for the application of renewable energy by biogas processes [14].

The prevailing relatively high electricity tariff (24.3 €cents/kWh compared to 5.1 €cents/kWh on the mainland) is expected to provide attractive returns for the project. The production of bio-fertilizer will result in additional revenue that further improves the project profitability. A connection of the electricity network on Phu Quoc to the national grid is considered as economically infeasible due to the long distance between the island and the mainland. The power supply of the island is provided by several old and new internal combustion engines burning diesel oil. According to the typical daily load curve of Phu Quoc, the daily peak load is about 3700 kW. Electricity production has increased approx. 4.8 times from 1998 to 2004 (nearly 30% annually).

In the near past, the environmental protection awareness of the people at Phu Quoc has not been high enough, leading to many uncontrolled landfills around the island's main conurbations. The household waste from the towns Duong Dong and An Thoi constitute the major part of the island's total waste production. The daily waste generation in semi-urban areas was estimated at 0.53 kg per capita or approximately 15.5 million kg annually in total. The composition of waste produced in the island of Phu Quoc is presented in Table 1.

There is also a wide range of suitable agriculture or forestry substrates available in the island that can be used for biogas or biomass production processes (cf. Table 2)

4. Selected options for RE production

Two different locations have been examined namely Cua Can (Site A) and Ham Ninh (Site B). Two different technological options

Table 1
Composition of waste to be used for renewable energy generation.

Components	Total waste (2005)	
	% wt	Mg
Paper	4.37	684
Glass	2.38	373
Metal	1.28	200
Plastic	8.05	1260
Food waste	53.36	8354
Garden waste	3.08	482
Shell, hulls, peel	10.77	1686
Wood waste	0.72	113
Other	16.10	2521
Total	100	15656

and a combination of them have been selected and assessed throughout this study.

4.1. Option 1

A dry fermentation technology [14,15] was found potentially suitable for the given framework conditions and has been assessed. Fig. 6 illustrates the simplified flow chart of a dry fermentation process. The technology of ‘‘dry fermentation’’ can generate energy from communal and agricultural biomass as well as organic waste. The substrate is delivered to the dry fermentation site where, if necessary, it is temporarily stored. A main characteristic of this dry fermentation process is that the input material can be used without further separation and pretreatment. The substrate is then mixed with already fermented matter that has been in one of the fermenters for several weeks. This is simply done outside the fermenters with the help of a wheel loader. Mixing, pumping and stirring equipment is not needed, thus reducing costs for investment and maintenance. One fermenter at a time is emptied and refilled in this way.

The combined block heat-and-power unit will be available for 95% of the time, equivalent to 8322 working hours per year. The 15,000 t/a of household waste constitute 35% of dry substance (which is 5250 t/a), of which 80% is organic dry substance. The organic dry substance has a specific biogas production rate of 0.4 m^3/t. These are the measures that are important for the actual energy generating content of the waste. Given these one can estimate that the block heat and power unit will produce 364 kW this is equivalent to 3192 MWh/a. There are basically two options dealing with the residue from biogas plant: disposing it at managed landfills or using it directly as fertilizer, whereby the relatively high quality compost, which results from the process of dry fermentation, is valuable for agricultural and horticultural purposes.

Table 2
Suitability of substrates from agriculture or forestry for biogas or biomass combustion processes ([+] means suitable or partially [(+)] suitable substrate, while [−] stands for unsuitable substrate).

Substrates	Suitability	
	Biogas process	Biomass combustion
Agro-based crop substrates		
Algae	+	+
Barley straw	(+)	+
Sugar beet	+	+
Blood meal	+	+
Cane trash	+	+
Clover	+	+
Coco bean shells	–	+
Elephant grass	(+)	+
Flax	(+)	+
Grass	+	–
Grass silage	+	–
Hay	+	+
Hemp	+	–
Maize silage	+	–
Maize straw	+	+
Oat straw	(+)	+
Peanut husk	–	+
Potato lops	+	+
Rape straw	+	+
Rapeseed shred	+	(+)
Rice husk	-	+
Rice straw	(+)	(+)
Sunflower leaves	+	–
Animal husbandry		
Cattle manure	+	–
Chicken manure	+	–
Horse manure	+	–
Pig manure	+	–
Sheep manure	+	–
		–
Forestry based residues		
Wood and wood residues	–	+

4.2. Option 2

The second technological option assessed has been a combination of a drying process (using solar energy) and a combustion plant with energy recovery by the innovative Pebble-Heater technology. A schematic overview of the pebble heater process is given in Fig. 7. The Pebble-Heater functions as a filter and reduces the emissions of dust, aerosols and tar by 50% compared to other technologies. The electricity output is estimated at about 1.2 MW_{el} for an overall input of 16,000 Mg waste per year. The solid output amounts to about 4% of the input only; it is biologically stabilized and free from smell, while no wastewater is produced.

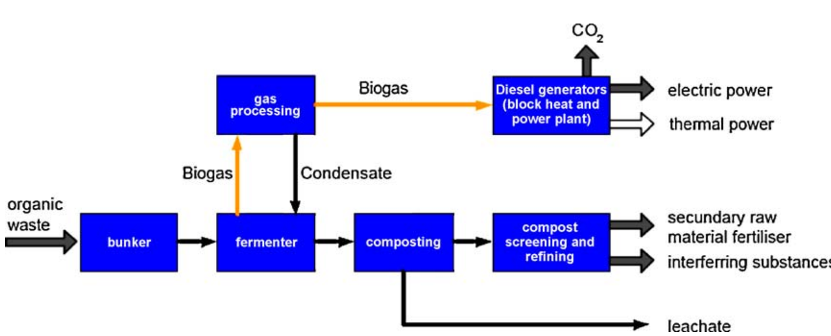

Fig. 6. Schematic diagram of the dry fermentation process, proposed as option 1.

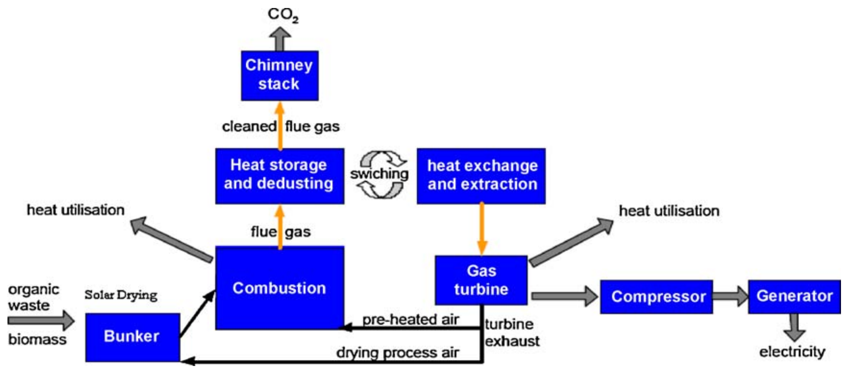

Fig. 7. Schematic diagram of the pebble heater process proposed as option 2.

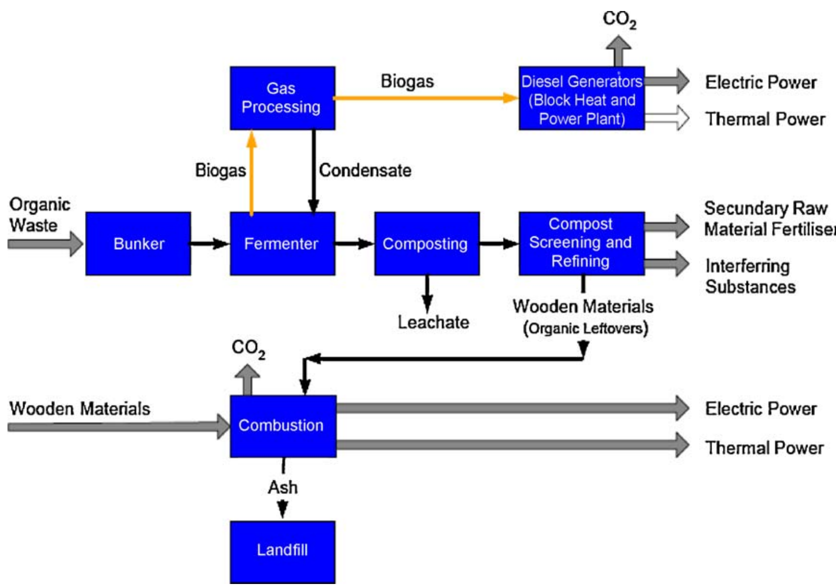

Fig. 8. Schematic diagram of the pebble heater process proposed as option 3.

4.3. Option 3

The third option was the idea to combine a biogas system with a combustion system in order to combine both previous options of energy generation (cf. Fig. 8) It was thought that it could be suitable for treating the household waste as well as separately collected wooden materials. Wooden materials can hardly be treated in a fermentation process and, thus, could be utilized in a biomass combustion system afterwards or – even better – separately. However, it was found early enough that it would not be feasible to implement both plants, a biogas and biomass combustion plant, in combination. The quantity of the output of the biogas plant will not be sufficient to represent the input for the combustion process which needs a minimum amount of input material to run economically. The wooden materials that can be supplied directly are not sufficient enough to be used in addition in order to meet the demand of total input material. For these profound reasons, the assessment of this option was terminated at an early stage.

5. Assessment of selected options

In order to help promote the use of renewable energy on the island, a systematic procedure to decision-making process should be provided to stakeholders involved in energy supply and local and regional decision-makers. For this to be fulfilled, the tools of Life Cycle Analysis (LCA) and risk assessment were used. An introduction of these tools is presented in this chapter as well as the results of the assessment of the two finally proposed options for renewable energy production for the island of Phu Quoc in Vietnam. The standard procedure for the use of LCA has been followed for each option. The system boundaries have been identified and analysis results have been produced. A commercial LCA software, namely GEMIS, has been used, which had an extensive database on energy production from biomass processes especially for developing countries. Most important factors that were taken into consideration were TOPP (Tropospheric Ozone Prevention Potential) equivalent, SO_2 equivalent emissions, CO_2 equivalent emissions, as well as particulates and NO_x emissions.

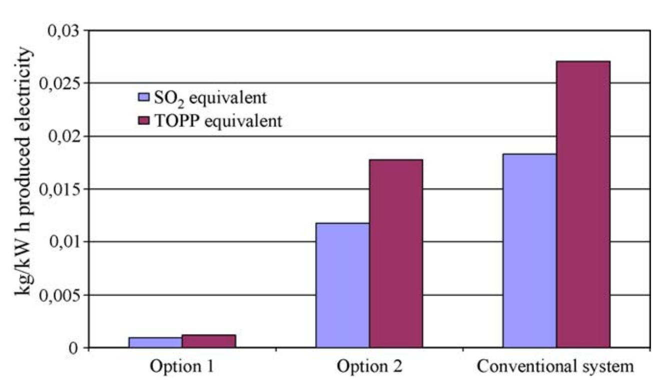

Fig. 9. TOPP and SO_2 equivalent emissions per kWh of produced electricity for each examined option compared to a conventional power generation system.

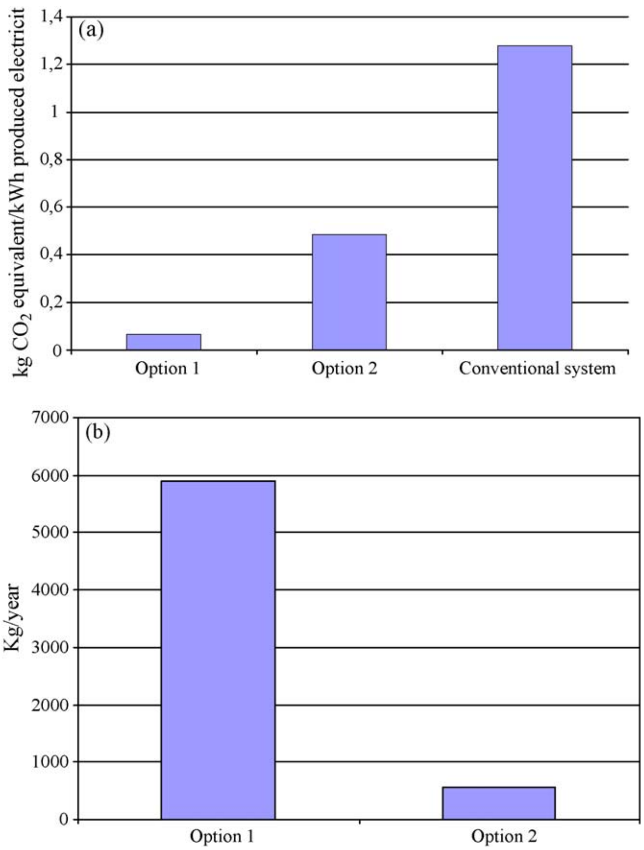

Fig. 10. CO_2 equivalent emissions per kWh of produced electricity (a) and annual production of NO_x emissions (b) for the two finally assessed options.

Moreover, other pollutants such as SO_2, CH_4, CO, non methane volatile organic compounds (NMVOC), H_2S, NH_3, as well as airborne As, Cd and Hg emissions were also calculated. The calculated emissions were compared to a conventional power producing unit using diesel fuel and the results concerning SO_2 and TOPP emissions are presented in Fig. 9, whereas Fig. 10 illustrates the production of CO_2 per kWh of produced energy along with the annual production of NO_x emissions for the two assessed options.

6. Conclusions

As main result of the assessment, it will be technically and economically feasible to implement a 500 kW dry fermentation biogas plant with an input of 15,000 tons household waste per year. The energy produced will be sufficient to substitute 13% of the current fossil energy source (diesel). Thus 16,700 tons CO_2-equiv. per year will be saved. Furthermore, the household waste from Phu Quoc will be treated anaerobically, so that major negative environmental impacts by uncontrolled waste disposal of untreated waste -the current practice- will be reduced. The solid output of the process will be further treated. A sieved and composted fraction can be utilised as fertiliser. The remaining material is sufficiently stabilised for disposal on a landfill site. A dry fermentation biogas plant will have a number of benefits:

- The modular dry fermentation process is more flexible than a combustion plant. It can be adapted easily to increasing waste quantities and changing waste composition to match future developments on Phu Quoc, e.g. due to increasing tourism.
- The biogas plant is operated as batch process and therefore can deal with short-term changing quantities of input material (e.g. small waste quantities in low tourism season).
- The type of waste, which will be used as input material, is characterized by high water content and therefore is more suitable for the utilization in a biogas plant.
- Compared to the combustion process, the biogas technology is more adapted to the level of development of Vietnam. Experiences with thousands of small-scale biogas plants, which exist all over the country, are a good basis to operate and maintain a large-scale biogas plant.
- The biogas plant will require less capital investment than the combustion plant.
- The biogas process supports the recycling of materials. A major fraction of the solid output is digested organic substrate, which can be utilized as fertilizer in local agriculture. As a consequence, the import of mineral fertilizer can be reduced and the soil quality can be improved.
- It can be expected that the acceptance for the biogas plant will be higher than for a combustion plant, since as mentioned, the biogas process is a well- known technology in Vietnam and is implemented with thousands of small-scale plants.

In addition to the recommendation of the favourable option, the feasibility of the other options that have been discussed will be summarized in the following. From the assessment it was concluded that it will also be feasible to implement a combustion process. Combining a solar drying process and a combustion plant with energy recovery by the innovative Pebble-Heater technology matches the requirements of Phu Quoc. The combination of the two technologies cannot be recommended due to lack in applicability and in the availability of suitable and sufficient feedstock. Even if material flow separation is applied, so that the wooden materials are combusted directly while the bio-waste is sent to the biogas process in the first stage, the quantity of the fermentation residues together with the wooden material will not be sufficient to represent the input for the combustion process, which needs a minimum amount of input material to run economically.

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